[redacted]

NACA

RESEARCH MEMORANDUM

AN EXPERIMENTAL INVESTIGATION OF THE APPLICABILITY OF THE HYPERSONIC SIMILARITY LAW TO BODIES OF REVOLUTION

By Stanford E. Neice and Thomas J. Wong

Ames Aeronautical Laboratory
Moffett Field, Calif.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

January 27, 1953

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

AN EXPERIMENTAL INVESTIGATION OF THE APPLICABILITY OF THE HYPERSONIC SIMILARITY LAW TO BODIES OF REVOLUTION

By Stanford E. Neice and Thomas J. Wong

SUMMARY

The hypersonic similarity law for steady flow about bodies of revolution is investigated by correlating the forces and moments from tests at Mach numbers from 2.75 to 5.00 and angles of attack from 0° to 25°. Included in the tests are cones and tangent ogives of thickness ratios from 0.143 to 0.333, and blunt-nosed bodies of thickness ratios of 0.200 and 0.333.

The data for the lifting cones and ogives are correlated by the hypersonic similarity law. The percentage error in these correlations is approximately equal to the inverse square of the Mach number, the square of the thickness ratio, or the square of the angle of attack (in radians), whichever is the largest. For nonlifting cones and ogives, the predictions of previous theoretical investigations are verified within the range of test parameters available.

For lifting blunt bodies, the results demonstrate that deviations from the predictions of the hypersonic similarity law increase with the degree of nose bluntness. In the nonlifting case, the deviations are found to be smaller and less sensitive to the degree of nose bluntness.

INTRODUCTION

The hypersonic similarity law for steady potential flow about thin airfoil sections and slender nonlifting bodies of revolution was first developed by Tsien in reference 1. Later, Hayes (reference 2) pointed out that the law should apply equally well when shock waves and vorticity appreciably influence the flow and reasoned that similitude could be obtained for flow about slender three-dimensional bodies of arbitrary shape.

[redacted]

In reference 3, the hypersonic similarity law was developed for steady inviscid flow about slender three-dimensional shapes. Also, in reference 3, for the special case of slender inclined bodies of revolution, the method developed by Allen (reference 4) was used to extend the law to include some significant effects of the viscous cross force.

Theoretical investigations to check the applicability of the hypersonic similarity law to nonlifting bodies of revolution were performed in references 5 and 6 by comparing pressure distributions obtained by the method of characteristics over related bodies. It was found that the law as applied to these bodies is accurate over a wide range of Mach numbers and thickness ratios even when shock waves and vorticity appreciably influence the flow. There has, however, been no similar investigation to check the accuracy of the law for inclined bodies of revolution. The determination of the flow over inclined bodies of revolution by the method of characteristics is an exceedingly time-consuming operation with procedures presently available. It seemed evident, therefore, that any extensive program to check the applicability of the hypersonic similarity law to such flows could better be carried out experimentally. An experimental investigation would, of course, include the effects of the viscous cross force, which the method of characteristics would not. The experimental approach would also provide a means of determining other effects of skin friction (which are not included in the derivation of the law) on the applicability of the law.

Results of a limited experimental investigation reported in reference 3 showed that the pressures acting on two inclined cones were properly related by the law. Further checks, however, are necessary to provide a larger measure of confidence in its applicability. Data required for such checks were obtained in the investigation reported in reference 7. In that investigation the aerodynamic characteristics of representative pointed and blunt bodies of revolution having thickness ratios from 0.143 to 0.333 were obtained at Mach numbers of 2.75 to 5.00 and angles of attack up to 25°.

The primary purpose of this research is to check the applicability of the hypersonic similarity law to pointed bodies of revolution by using the experimental data of reference 7. The secondary purpose of this research is to investigate the effect of nose bluntness upon the applicability of the hypersonic similarity law by considering the series of blunt-nosed bodies also reported in reference 7.

SYMBOLS

A	maximum cross-sectional area of body
c	length of body
c_{d_c}	section drag coefficient of circular cylinder with axis perpendicular to the flow
$\widehat{c_{d_c}}$	mean c_{d_c} for a body of revolution
C_D	drag coefficient $\left(\dfrac{\text{drag}}{q_oA}\right)$
$\widetilde{C_D}$	drag parameter $(M_o{}^2C_D)$
$\widetilde{C_D}'$	drag parameter $(M_o{}^2C_D)$ corrected for skin-friction effects
C_L	lift coefficient $\left(\dfrac{\text{lift}}{q_oA}\right)$
$\widetilde{C_L}$	lift parameter (M_oC_L)
C_m	pitching-moment coefficient $\left(\dfrac{\text{pitching moment about axis through the base}}{q_oAc}\right)$
$\widetilde{C_m}$	pitching-moment parameter (M_oC_m)
K_t	hypersonic similarity parameter $(M_o \frac{t}{c})$
K_α	hypersonic similarity parameter $(M_o\alpha)$, degrees
M	Mach number
p	static pressure
q	dynamic pressure
r	radius of body at any station x

R_c cross Reynolds number based on maximum body diameter and the component of the free-stream velocity normal to the body axis

t maximum thickness of body

$\frac{t}{c}$ thickness ratio of body

x,y,z Cartesian coordinates

α angle of attack, degrees

Subscripts

o free-stream conditions

v viscous cross-force effects

SUMMARY OF THE HYPERSONIC SIMILARITY LAW

The hypersonic similarity law for inviscid flow about slender three-dimensional shapes at small angles of attack, excluding the effects of base force, may be stated as follows (see reference 3): To have similarity of flow about related bodies, the lateral dimensions of these bodies and their angles with respect to the flight direction must be inversely proportional to their flight Mach numbers. This law permits the aerodynamic coefficients of slender bodies of revolution to be expressed in the following functional form:

$$\left.\begin{aligned} M_o C_L &\equiv \widetilde{C_L} = \widetilde{C_L}(K_t, K_\alpha) \\ M_o^2 C_D &\equiv \widetilde{C_D} = \widetilde{C_D}(K_t, K_\alpha) \\ M_o C_m &\equiv \widetilde{C_m} = \widetilde{C_m}(K_t, K_\alpha) \end{aligned}\right\} \qquad (1)$$

Thus the corresponding force and moment parameters have identical values for related bodies of revolution, provided the corresponding similarity parameters, K_α and K_t, have identical values. If the angle of attack is zero, K_α is also zero, and the expression for the drag parameter reduces to a form equivalent to that obtained by Tsien (reference 1).

The hypersonic similarity law for slender bodies of revolution can be generalized to include significant effects of viscous cross force.

In reference 3, expressions for the aerodynamic coefficients resulting from the viscous cross force (see reference 4) are combined with the inviscid forms as given by equation (1). The resulting expressions are:

$$\left.\begin{aligned}\widetilde{C_L} &= \widetilde{C_L}(K_t, K_\alpha, R_c)\\ \widetilde{C_D} &= \widetilde{C_D}(K_t, K_\alpha, R_c)\\ \widetilde{C_m} &= \widetilde{C_m}(K_t, K_\alpha, R_c)\end{aligned}\right\} \qquad (2)$$

where the cross-flow Reynolds number, R_c, is an additional similarity parameter.

EXPERIMENTAL CONSIDERATIONS

The aerodynamic characteristics, excluding the effects of base force, of all models used in this investigation were obtained in the Ames 10- by 14-inch supersonic wind tunnel and previously presented in reference 7.

The models tested are shown in figure 1. The first group (fig. 1(a), sharp-nosed models) consisted of four cones of thickness ratios 0.333, 0.250, 0.200, and 0.143, and three tangent ogives of thickness ratios 0.333, 0.200, and 0.143. A second group consisted of two sets of blunt bodies, one of thickness ratio 0.333 and one of thickness ratio 0.200, in each set. The meridian sections of these bodies are defined by the equations

$$\frac{r}{t/2} = \left(\frac{x}{c}\right)^{3/4} \quad \text{(3/4-power bodies)} \qquad (3)$$

$$\frac{r}{t/2} = \left(\frac{x}{c}\right)^{1/2} \quad \text{(1/2-power bodies)} \qquad (4)$$

These blunt bodies are shown in figure 1(b); the bodies defined by equation (3) are shown on the left and those defined by equation (4) on the right. All models were of polished steel and had base diameters of 1 inch.

Force, moment, and base pressure measurements were taken at 2° or 3° intervals of angle of attack up to 25° and at Mach numbers of 2.75, 4.01, and 5.00. Uncertainties in these measurements were shown in reference 7 to result in maximum probable errors in lift, drag, and pitching-moment coefficients at high angles of attack of ±0.008 at Mach numbers 2.75

and 4.01, and ±0.035 at Mach number 5.00. At small angles of attack the corresponding maximum probable errors were ±0.004 and ±0.015, respectively.

TREATMENT OF DATA

Method of Presentation

Lifting bodies of revolution.- The hypersonic similarity law for lifting bodies of revolution, as given by equation (2), states that the aerodynamic parameters, $\widetilde{C_L}$, $\widetilde{C_D}$, and $\widetilde{C_m}$, remain unchanged for related bodies provided the similarity parameters remain constant. An appropriate way to investigate the applicability of the similarity law is to plot the aerodynamic parameters for related bodies as a function of K_α and R_c for given values of K_t. If the hypersonic similarity law were completely applicable, these curves would be coincident. Hence, the proximity of these curves to each other is a measure of the degree of applicability.

From the experimental data of reference 7, the variation of the lift, drag, and pitching-moment parameters with K_α for various values of K_t can be established. Cross-plotting, interpolating and, in two instances, extrapolating from Mach number 2.75 to 2.5 was required to get the data in suitable form for comparison. The values of K_t, Mach number, and thickness ratio for each type of related body are as follows:

Body	K_t	M_o	t/c
Cones	0.50	2.5	0.200
		3.5	.143
	1.00	3.0	.333
		4.0	.250
		5.0	.200
	1.25	3.75	.333
		5.00	.250
Ogives	.50	2.5	.200
		3.5	.143
	1.00	3.0	.333
		5.0	.200
Blunt-nosed bodies	1.00	3.0	.333
		5.0	.200

Nonlifting bodies of revolution.- The hypersonic similarity law for nonlifting bodies of revolution states that the drag parameter, $\widetilde{C_D}$, for related bodies is a function only of the similarity parameter K_t. Therefore, a plot of the drag parameter as a function of K_t for several related bodies should result in a single curve. The degree to which experimental points satisfy this criterion is a measure of the degree of applicability of the law for this case. The experimental data of reference 7 are used directly by putting them into this form.

Reynolds Number Effects

Cross-flow effects.- As shown in reference 3, the change in force and moment parameters with cross-flow Reynolds number depends primarily upon the variation of the coefficient $\widehat{c_{d_c}}$ with R_c. The variation of the circular-cylinder drag coefficient c_{d_c} (see reference 4), as well as the mean value for the body of revolution $\widehat{c_{d_c}}$, is a very weak function of the cross-flow Reynolds number in the range from 8×10^3 to 2×10^5. With the maximum test Reynolds numbers available (see fig. 2), the maximum cross-flow Reynolds number obtained in the tests of reference 7 did not exceed the value of 2×10^5, while the viscous cross-force effect is negligible below a value of 8×10^3. Consequently, the effects of the variation of R_c will be considered negligible within the range of Mach numbers, Reynolds numbers, and angles of attack encountered in this investigation.

Other boundary-layer effects.- The effects of boundary layer on the zero-lift drag characteristics of a body are not included in the derivation of the hypersonic similarity law. In order to estimate these effects in the case of nonlifting cones, the skin-friction drag coefficient and the displacement thickness were calculated using the methods of references 8 and 9. The boundary-layer displacement thickness was used to correct the thickness ratio of the body.

The data of reference 10 indicate that, for laminar flow, the skin-friction drag coefficient of an ogive, based on wetted area, is approximately equal to that of a cone of the same length and thickness ratio. In view of this, the values of skin-friction drag for ogives were evaluated by increasing the value of the skin-friction drag for cones of the same thickness ratio by the ratio of the surface areas. The value of boundary-layer displacement thickness applied to ogives was the same as that obtained for cones of the same thickness ratio.

In the correction for the boundary-layer effects for the blunt bodies, the procedure employed was the same as that for ogives. Inasmuch as the dimensions of the 3/4-power bodies are, except in the vicinity of the nose, close to those of the cones of the same thickness ratio, the boundary-layer corrections should be reliable. The 1/2-power body is considerably more blunt than the 3/4-power body. Consequently, the procedure for estimating the boundary-layer effects cannot be considered reliable when applied to this shape.

Condensation Effects

A reduction in the values of the aerodynamic parameters at Mach number 5.00 is caused by the evaporation of small amounts of condensed air present in the stream. This effect was investigated experimentally in reference 11 for a wedge airfoil and a nonlifting body of revolution. The effect of evaporation on the surface pressure of the particular bodies tested was found to be of the same order of magnitude as, but opposite in sign to, the effects of the boundary layer. Further investigation, for the purposes of this report, indicates that the correction to be applied for the cones, throughout the angle-of-attack range at Mach number 5.00, is about 7 percent for the lift and pitching-moment parameters and 3 percent for the drag parameter. These corrections were applied to all bodies.

RESULTS AND DISCUSSION

Following the procedure outlined in the previous section, the variations of the aerodynamic force and pitching-moment parameters $\widetilde{C_L}$, $\widetilde{C_D}$, $\widetilde{C_m}$ with the similarity parameter K_α at given values of K_t were obtained for the cones, ogives, and blunt bodies under consideration. The results are presented in figures 3 through 6. In these figures, no correction has been applied for the effects of skin friction and boundary-layer displacement thickness.

The applicability of the hypersonic similarity law is first considered in detail with regard to lift and pitching moment. Drag, including effects of skin friction, is then treated.

Similitude for Lift and Pitching Moment

Cones and ogives.- The percent deviation between each pair of lift and moment parameter curves for cones and ogives (figs. 3 and 4) is plotted as a function of K_α in figures 7 and 8, respectively. For the most part, the hypersonic similarity law for inclined cones and ogives appears to be somewhat more accurate for lift than for moment.

From these deviation curves it can also be seen that the degree of correlation can be estimated from consideration of the magnitude of the errors inherent in the development of the hypersonic similarity law. In the development of the law (see reference 3), terms of the order of $1/M_o^2$, $(t/c)^2$, and α^2 (in radians) are neglected with respect to 1. Maximum errors of the order of magnitude of the largest term might therefore be anticipated in the practical application of the law.[1] As an example, consider the correlation of the lift and moment parameter curves for bodies of thickness ratios 0.333 and 0.200 at Mach numbers of 3.0 and 5.0, respectively ($K_t = 1.0$, figs. 7 and 8). The maximum error to be expected would be in the neighborhood of $(0.333)^2$ or 11 percent at angles of attack below 0.333 radians or 19°, corresponding to a value of K_α of 57.3°. For cones (fig. 7) the lift-parameter deviation increases to a value of 11 percent at a corresponding value of K_α of about 50°, as compared to the predicted value of 57.3°. The moment-parameter deviation curve for cones, except for very low values of K_α, is about 3 to 5 percent higher than the predicted error. A similar trend is found for the ogives in figure 8. The lift-parameter deviation increases to a value of 11 percent at a value of K_α of 45°, while the pitching-moment-parameter deviation curve is 2 to 6 percent higher than the predicted maximum value throughout the range of K_α. From similar considerations of the remaining deviation curves for cones and ogives, it appears that the predicted error provides a good estimate of the upper limit of deviation to be anticipated in the case of lift, while presenting a somewhat less reliable (generally too low) estimate for the case of pitching moment.

<u>Blunt-nosed bodies</u>.- The percent deviations of the lift and pitching-moment-parameter curves for blunt bodies at $K_t = 1.0$ are plotted as a function of K_α in figure 9. Comparison of the curve for the 3/4-power body with the corresponding curves for cones and ogives indicates that the hypersonic similarity law as applied to lift is somewhat less accurate for the 3/4-power body. For lower values of K_α, however, the law applies equally well to the 3/4-power body and the cone. For pitching moment, however, better accuracy is obtained for the 3/4-power body than for either cones or ogives. Within the range of similarity parameters considered, then, the slight amount of bluntness presented by the 3/4-power body does not appear to have a serious effect on the applicability of the hypersonic similarity law to lift and pitching moment.

The large deviations, however, in the lift and moment parameter curves for the 1/2-power body, as shown in figures 6 and 9, indicate that the degree of bluntness presented by this body is sufficient to render the hypersonic similarity law significantly less applicable to these parameters.

[1]This point was also brought out in reference 12 where it is shown that errors of similar order of magnitude are to be anticipated with regard to rotational hypersonic flow about thin airfoils.

Similitude for Drag

The curves of $\widetilde{C_D}$ as a function of K_α, presented in figures 3 through 6, show severe departures from each other. It might be expected that, at lower values of K_α, these departures are, at least for the sharp-nosed bodies, due primarily to effects of skin friction not included in the theoretical development of the law. Since boundary-layer characteristics can be determined relatively accurately in the nonlifting case (references 8 and 9), it is feasible to investigate this point. In figures 10 through 13 $\widetilde{C_D}'_{\alpha=0}$ is plotted as a function of K_t for all bodies tested at Mach numbers 2.75, 4.01, and 5.00. In these figures corrections have been applied, in the manner discussed previously, for the effects of boundary layer. To illustrate the magnitude and importance of these corrections, the uncorrected values are presented for cones in figure 10(a). It can be seen that the correction for skin friction is about five times larger than the correction for distortion of the body as determined from the boundary-layer displacement thickness.

Cones and ogives.- If the hypersonic similarity law is applicable for related bodies at zero angle of attack, values of $\widetilde{C_D}'_{\alpha=0}$, plotted in the manner indicated above, should lie along a single curve. Such curves for cones and ogives were determined theoretically in references 5 and 6, respectively, and are presented in figures 10 and 11. The experimental points, for the most part, lie very close to the theoretical curves. The discrepancy indicated by the points for the cone and ogive of thickness ratio 0.143 at Mach numbers 2.75 and 4.01, which lie somewhat above the curves, is believed to be caused by boundary-layer transition over the rearward part of the body.

The curves of $\widetilde{C_D}$ as a function of K_α presented in figures 3 and 4 are approximately parallel throughout the lower range of K_α. This observation along with the high degree of accuracy evidenced in the nonlifting case indicates that, after the zero-lift boundary-layer effects have been subtracted, the hypersonic similarity law for drag of inclined cones and ogives should be applicable throughout the lower range of K_α to the same degree of accuracy evidenced in references 5 and 6. This indication was checked for cones at $K_t = 1.0$ and the results are presented in figure 14.

With respect to the order of magnitude of terms neglected in the development of the law, the maximum correlation error to be anticipated in this case is again 11 percent at angles of attack below 0.333 radians or 19°, corresponding to a value of K_α of 57.3°. This prediction is verified by the results presented in figure 14.

Blunt-nosed bodies.- No theoretical curve for the variation of $\widetilde{C_D}'_{\alpha=0}$ with K_t has been established for either class of related blunt-nosed bodies. However, a surprising degree of accuracy of the hypersonic similarity law as applied to drag at zero angle of attack is indicated in figures 12 and 13. A single curve can be faired which passes very close to the experimental points in either case.

Throughout the range of K_t from approximately 0.6 to 1.7, the experimental curve of $\tilde{C}_{D'_{\alpha=0}}$ as a function of K_t for the 3/4-power body is 15 to 18 percent lower than the theoretical curve for cones. This percentage difference corresponds to that determined both theoretically and experimentally in reference 13 for the same range of thickness ratios and Mach numbers. The experimental curve for the 1/2-power body is almost coincident with the theoretical curve for cones. This feature has also been observed in reference 13.

It should be pointed out, however, that there is an insufficient amount of overlapping experimental values in both figures 12 and 13 to determine decisively whether the points actually form a single curve. At best, it can only be stated that there is the indication that the hypersonic similarity law, as applied to the drag of these blunt-nosed bodies at zero angle of attack, is accurate within the range of K_t considered.

The drag parameter curves in figures 5 and 6 diverge at higher values of K_α, indicating that the hypersonic similarity law, as applied to the drag (corrected for boundary-layer effects) over these lifting bodies, is applicable only in the lower ranges of K_α to the same degree of accuracy as indicated in the zero angle-of-attack case.

CONCLUDING REMARKS

The data for cones and ogives, excluding the effects of base pressure, are correlated by similarity law. The percentage error in these correlations is approximately equal to $1/M_o^2$, $(t/c)^2$, and α^2 (in radians), whichever is the largest. The effects of skin friction not included in the derivation of the law are not large enough to affect significantly the applicability of the hypersonic similarity law for lift and pitching moment within the range of Reynolds numbers obtained in the tests. However, skin-friction drag comprises a large part of the total drag and a correction for this effect is necessary.

Deviation from the hypersonic similarity law as applied to blunt-nosed bodies depends on the degree of nose bluntness. The 3/4-power blunt body exhibits the same degree of applicability as indicated for cones and ogives, whereas the greater degree of bluntness presented by the 1/2-power body renders the hypersonic similarity law considerably less applicable for lift and pitching moment. For drag at zero angle of attack, however, both classes of blunt bodies exhibit the same degree of accuracy as indicated for cones and ogives, although sufficient experimental data are not available to establish this point conclusively.

It should be recognized that the results examined in this report were for simple bodies of revolution, and that before general statements regarding the applicability of the law in the three-dimensional lifting case can be made, more complex shapes including wing-body combinations must be investigated. It should also be pointed out that other methods of correlation may prove useful. For example, correlation with respect to thickness ratio alone, as indicated by the form of the law in the infinite Mach number case, might be used with satisfactory accuracy for some shapes. A cursory examination of the data has indicated that this may be true, especially in case of lift and moment acting on bodies of revolution at Mach numbers above about 4.

Ames Aeronautical Laboratory
National Advisory Committee for Aeronautics
Moffett Field, Calif.

REFERENCES

1. Tsien, Hsue-shen: Similarity Laws of Hypersonic Flows. Jour. Math. and Phys. Vol. 25, no. 3, Oct. 1946.

2. Hayes, Wallace D.: On Hypersonic Similitude. Quart. Appl. Math. Vol. V, no. 1, April 1947.

3. Hamaker, Frank M., Neice, Stanford E., and Eggers, A. J., Jr.: The Similarity Law for Hypersonic Flow About Slender Three-Dimensional Shapes. NACA TN 2443, 1951.

4. Allen, H. Julian: Estimation of the Forces and Moments Acting on Inclined Bodies of Revolution at High Fineness Ratio. NACA RM A9I26, 1949.

5. Ehret, Dorris M., Rossow, Vernon J., and Stevens, Victor I.: An Analysis of the Applicability of the Hypersonic Similarity Law to the Study of Flow About Bodies of Revolution at Zero Angle of Attack. NACA TN 2250, 1950.

6. Rossow, Vernon J.: Applicability of the Hypersonic Similarity Rule to Pressure Distributions Which Include the Effects of Rotation for Bodies of Revolution at Zero Angle of Attack. NACA TN 2399, 1951.

7. Dennis, David H., and Cunningham, Bernard E.: Forces and Moments on Pointed and Blunt-Nosed Bodies of Revolution at Mach Numbers From 2.75 to 5.00. NACA RM A52E22, 1952.

8. Hantzsche, W., and Wendt, H.: The Laminar Boundary Layer of a Circular Cone In Supersonic Flow at Zero Angle of Attack. Trans. by Ronald Kay; M. W. Rubesin, ed., Univ. of Calif., Berkeley, Engr. Res. Proj., 1947.

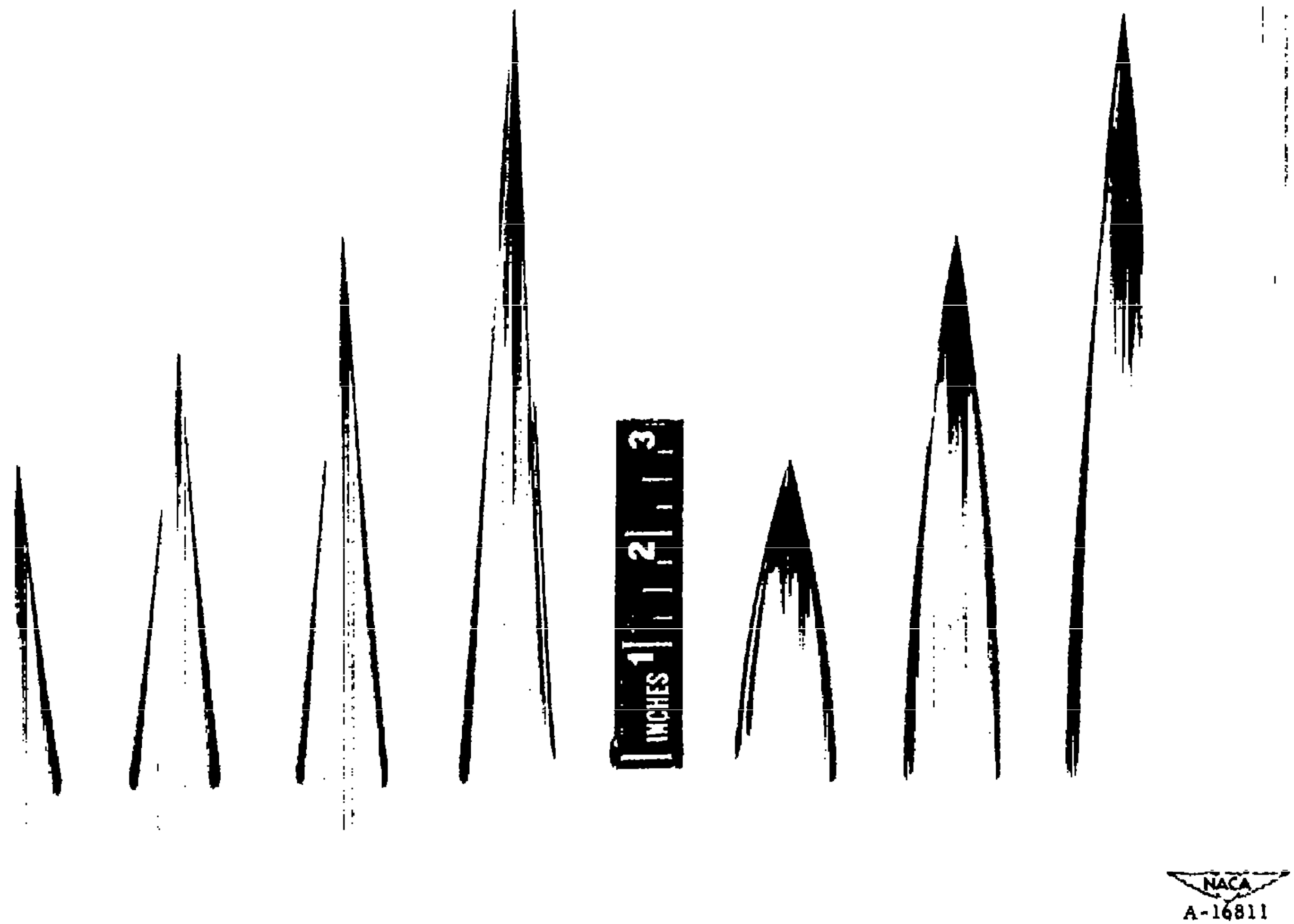
9. Monaghan, R. J.: An Approximate Solution of the Compressible Laminar Boundary Layer on a Flat Plate. TN No. Aero. 2025, Sup. 96, R.A.E. (British), 1949.

10. Jack, John R., and Burgess, Warren C.: Aerodynamics of Slender Bodies at Mach Number of 3.12 and Reynolds Numbers from 2×10^6 to 15×10^6. I - Body of Revolution With Near-Parabolic Forebody and Cylindrical Afterbody. NACA RM E51H13, 1951.

11. Hansen, C. Frederick, and Nothwang, George J.: Condensation of Air in Supersonic Wind Tunnels and Its Effects on Flow About Models. NACA TN 2690, 1952.

12. Goldsworthy, F. A.: Two-Dimensional Rotational Flow at High Mach Number Past Thin Aerofoils. Quart. Jour. Mech. and Appl. Math. Vol. V, pt. 1, March 1952.

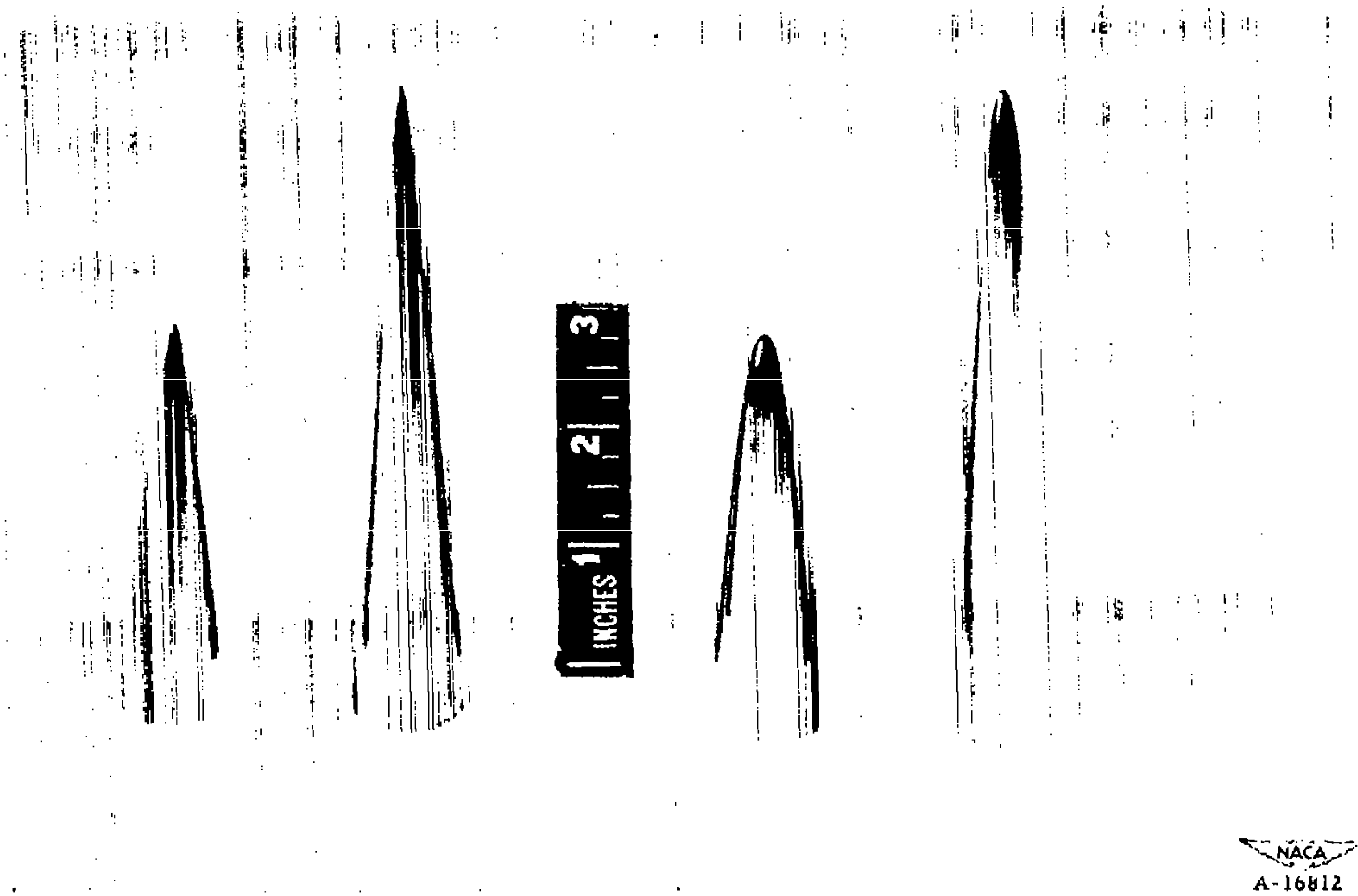
13. Eggers, A. J., Jr., Dennis, David H., and Resnikoff, Meyer M.: Bodies of Revolution for Minimum Drag at High Supersonic Airspeeds. NACA RM A51K27, 1952.



Cones: t/c 0.333, 0.250, 0.200, and 0.143 Ogives: t/c 0.333, 0.200, and 0.143

(a) Sharp-nosed bodies of revolution.

Figure 1.– Test models.



3/4-power bodies: t/c 0.333 and 0.200 1/2-power bodies: t/c 0.333 and 0.200

(b) Blunt-nosed bodies of revolution.

Figure 1.– Concluded.

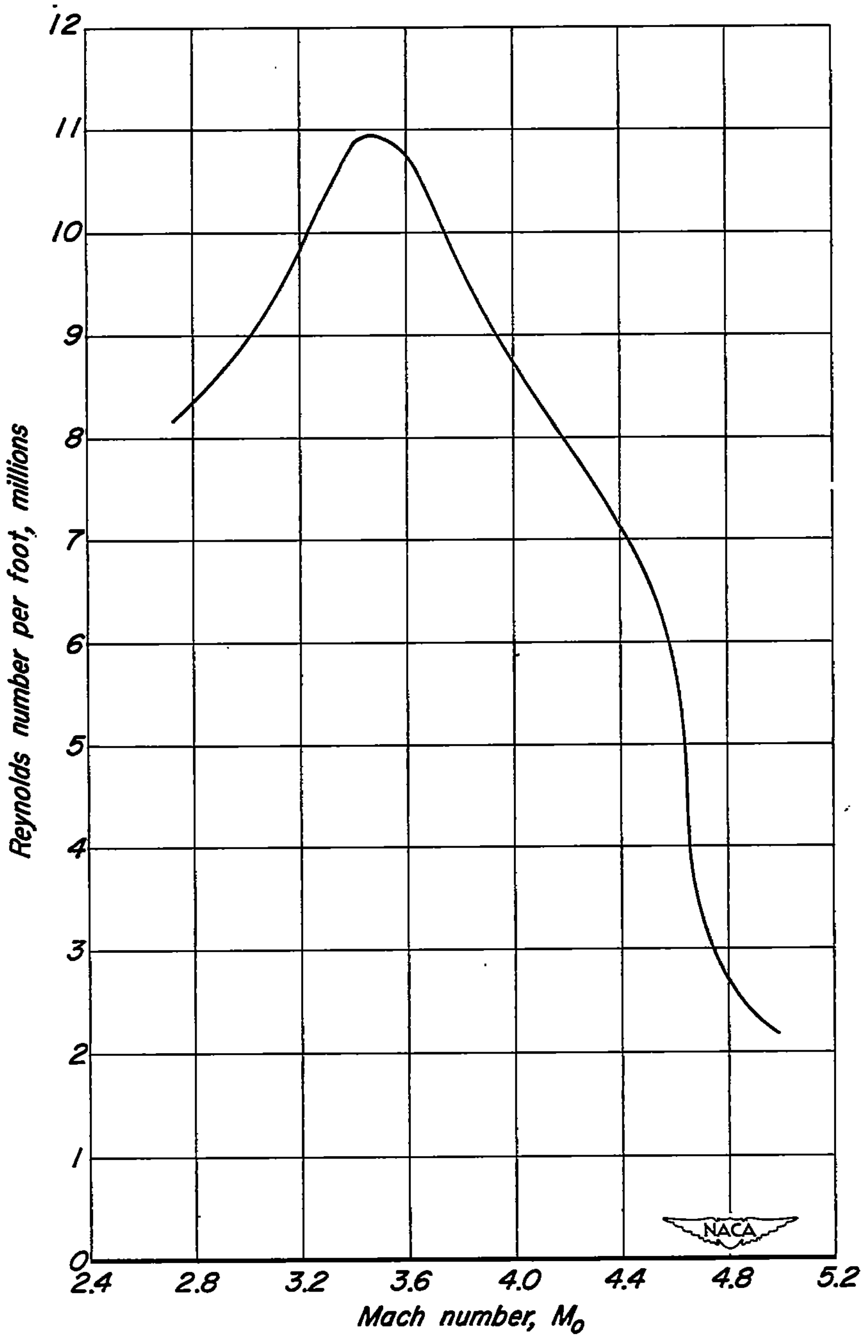
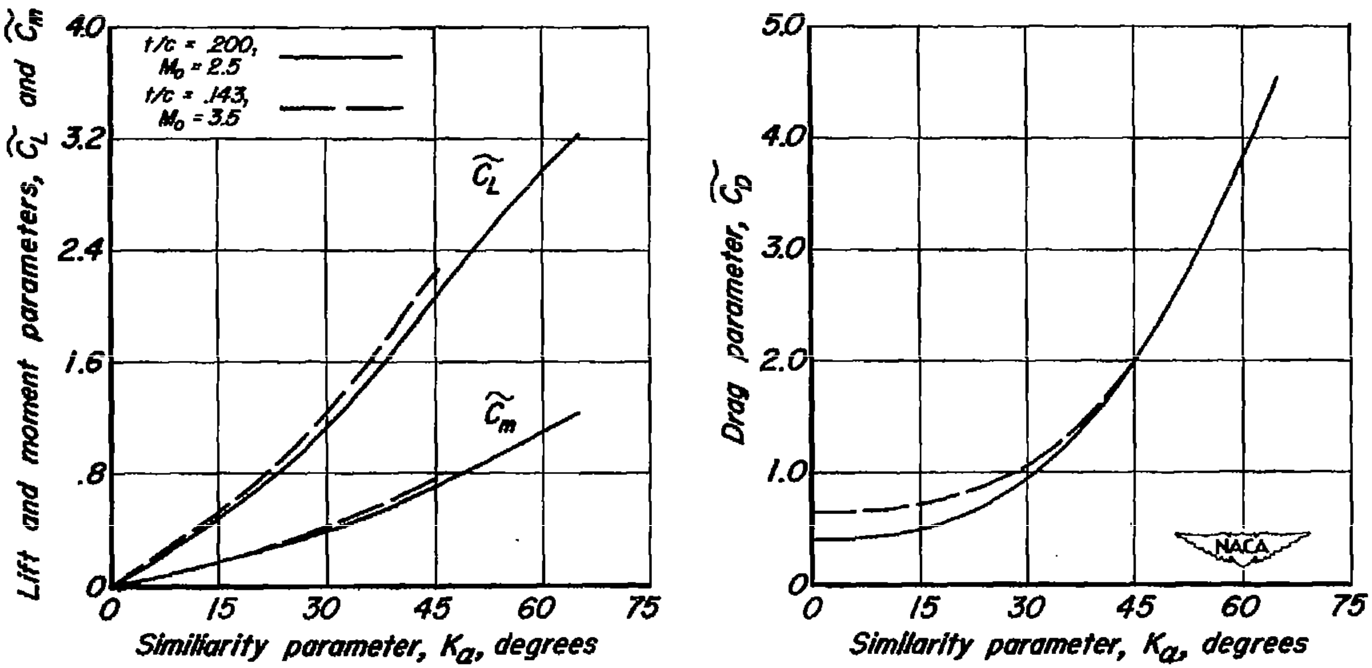


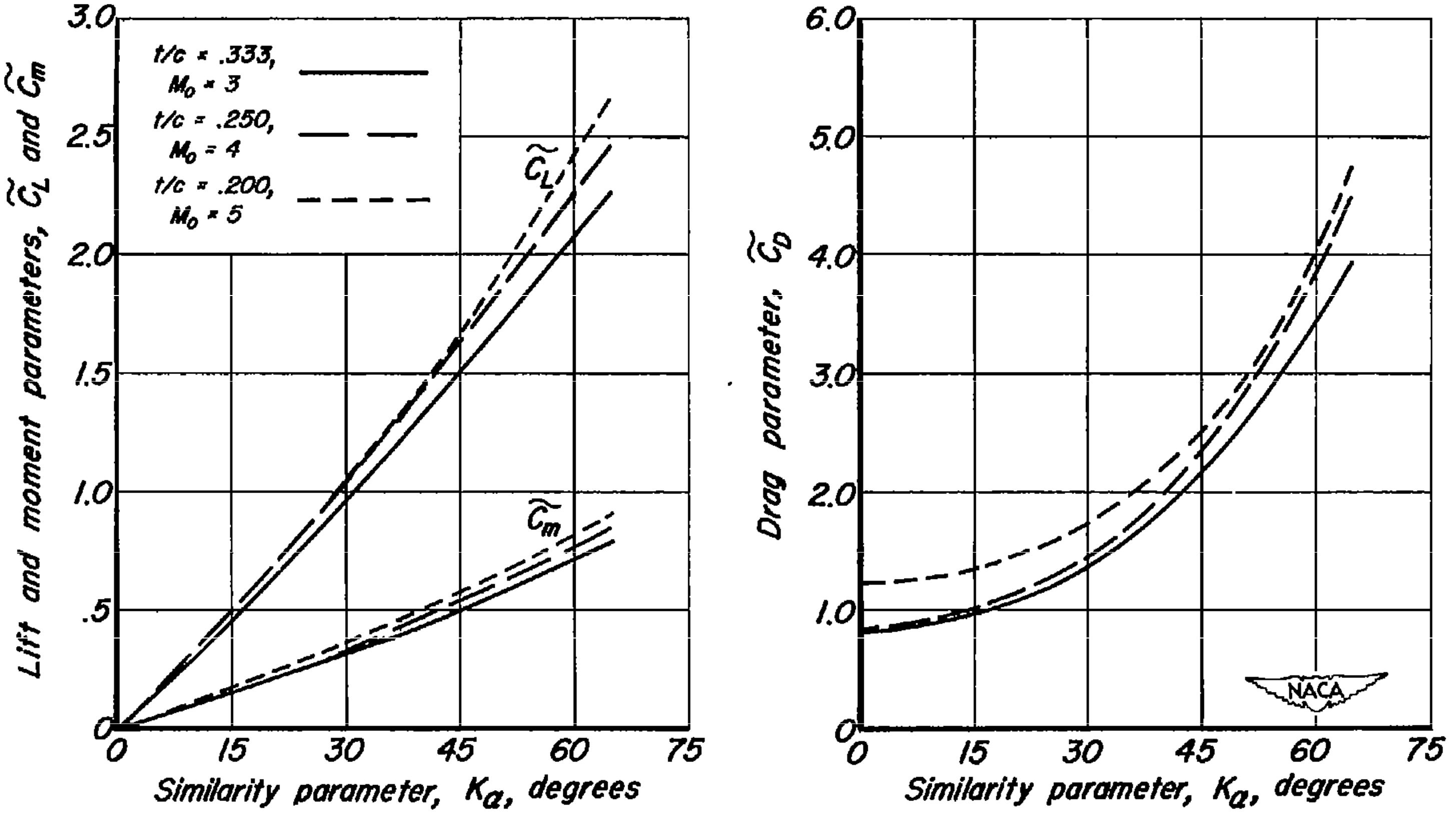
Figure 2.-Variation of Reynolds number with Mach number in the Ames 10- by 14- inch supersonic wind tunnel.

[redacted]



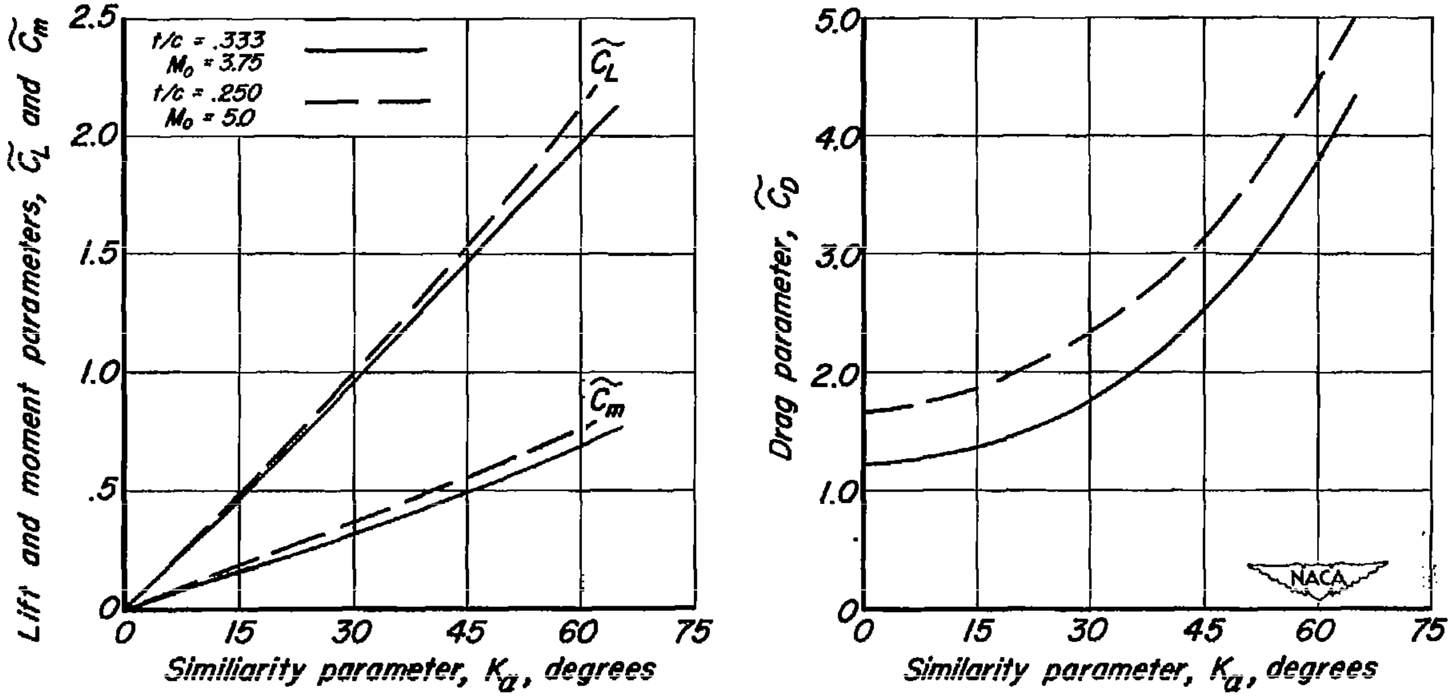
(a) $K_t = 0.5$

Figure 3.-Variation of the lift, drag, and moment parameters with K_α for cones at various values of K_t.



(b) $K_t = 1.0$

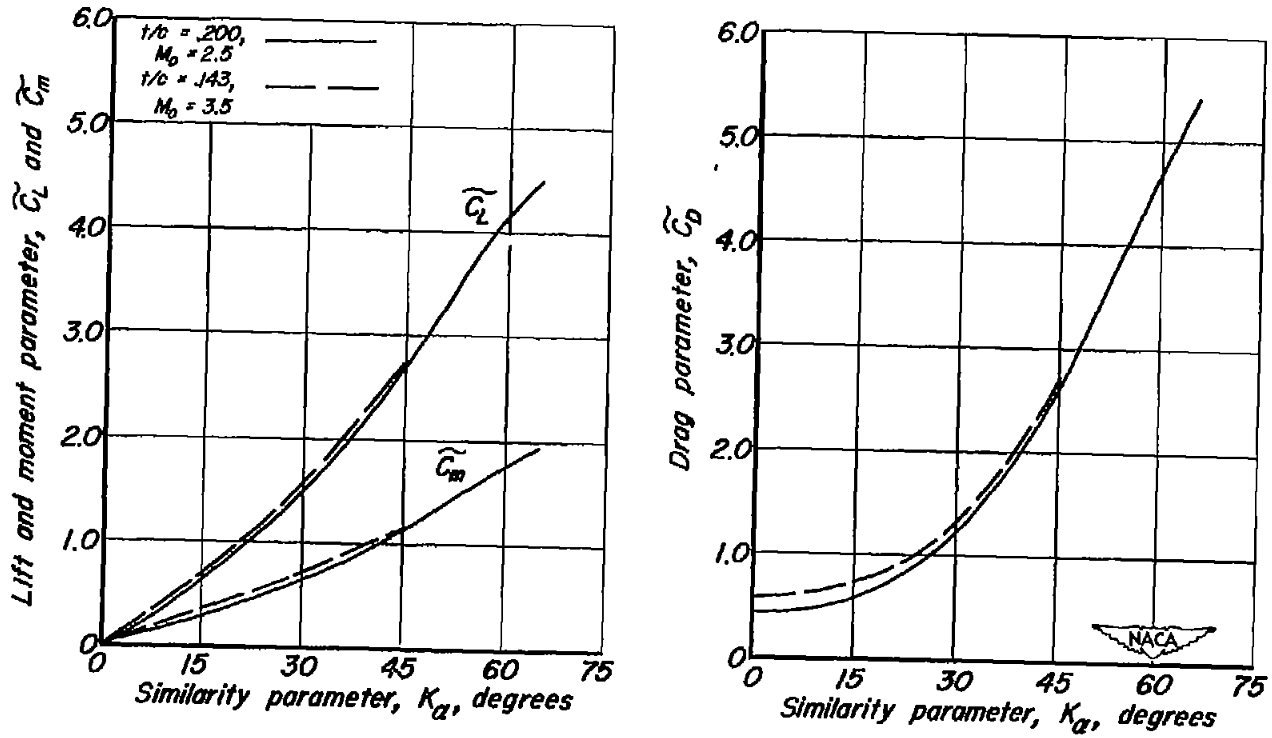
Figure 3.- Continued.



(c) $K_t = 1.25$

Figure 3.-Concluded.

[redacted]

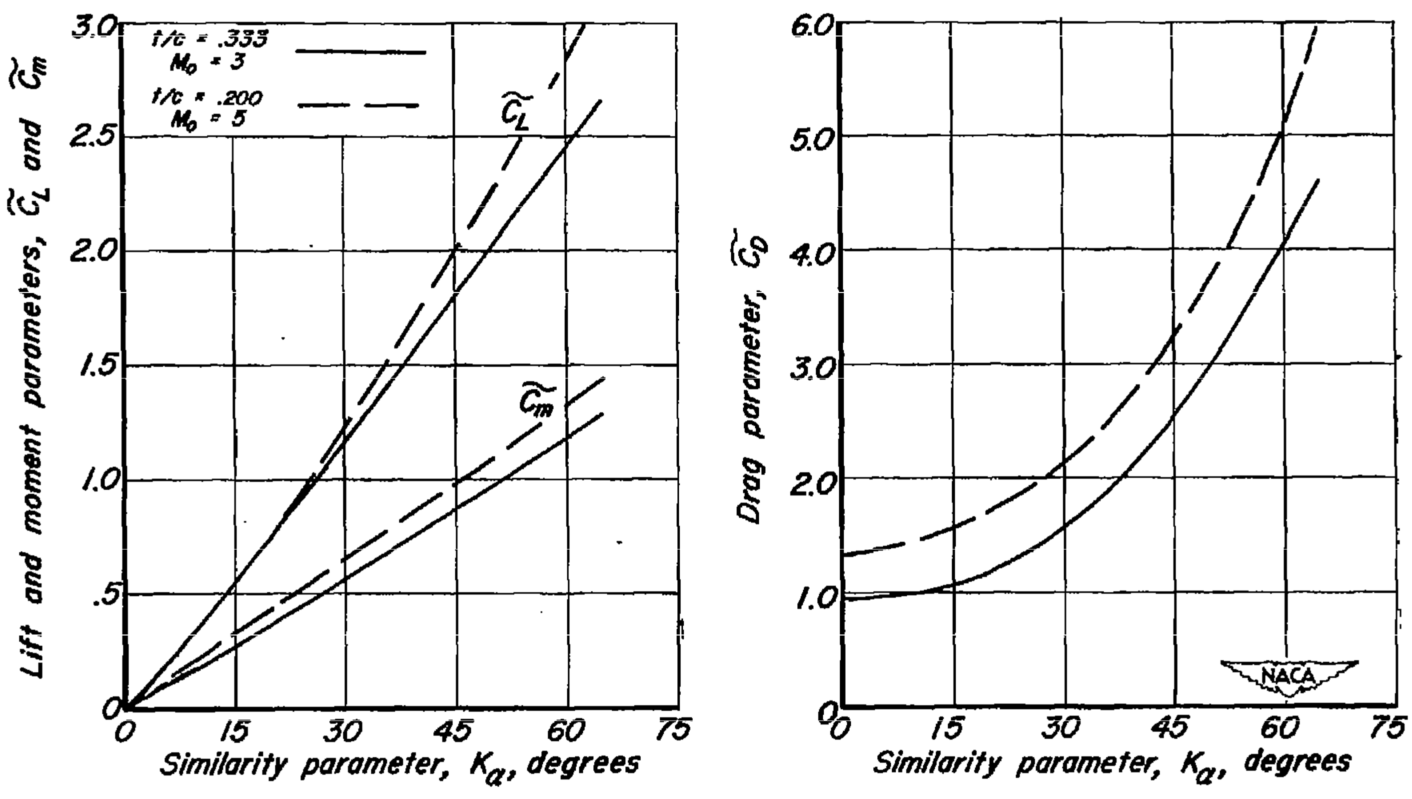


(a) $K_t = 0.5$

Figure 4.-Variation of the lift, drag, and moment parameters with K_a for ogives at various values of K_t.

[redacted]

[redacted]



(b) $K_t = 1.0$

Figure 4.-Concluded.

[redacted]

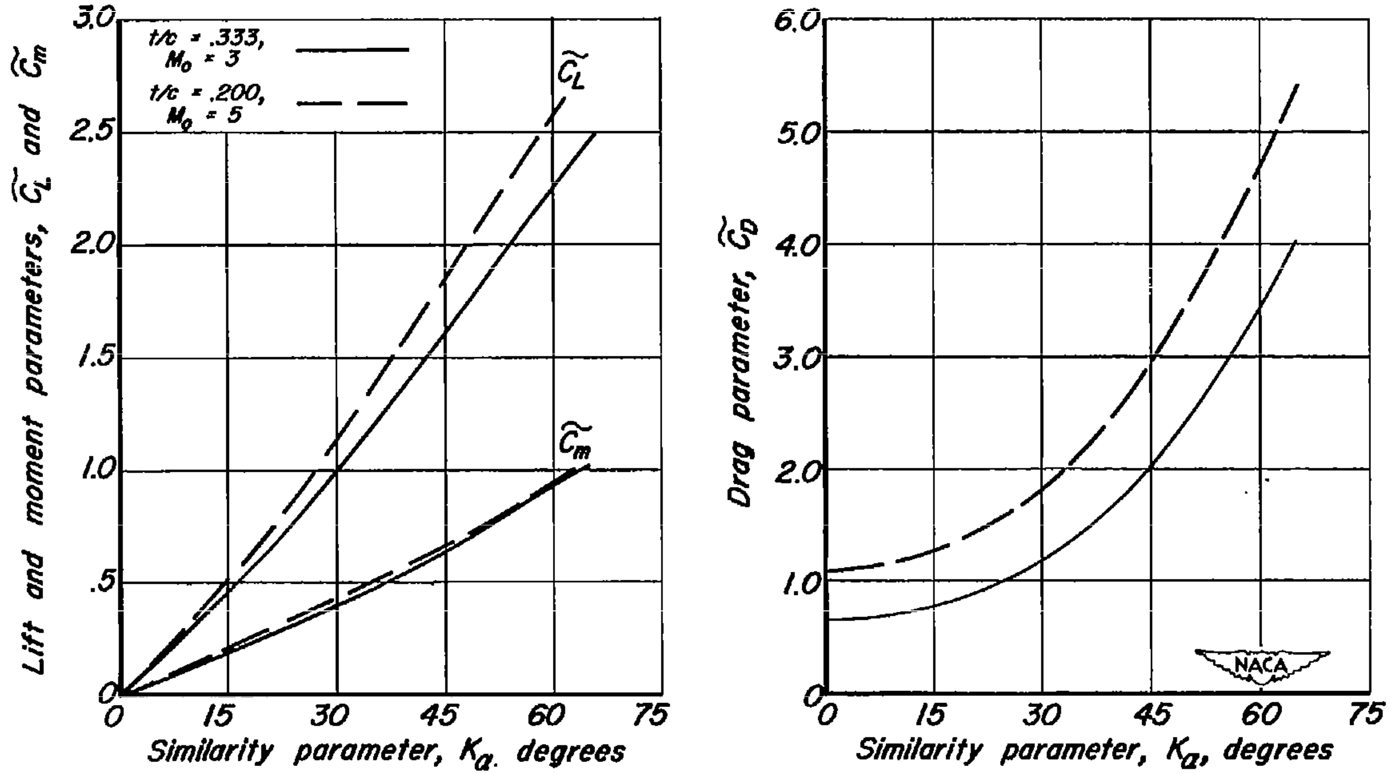


Figure 5.-Variation of the lift, drag, and moment parameters with K_α for 3/4-power bodies at K_t = 1.0.

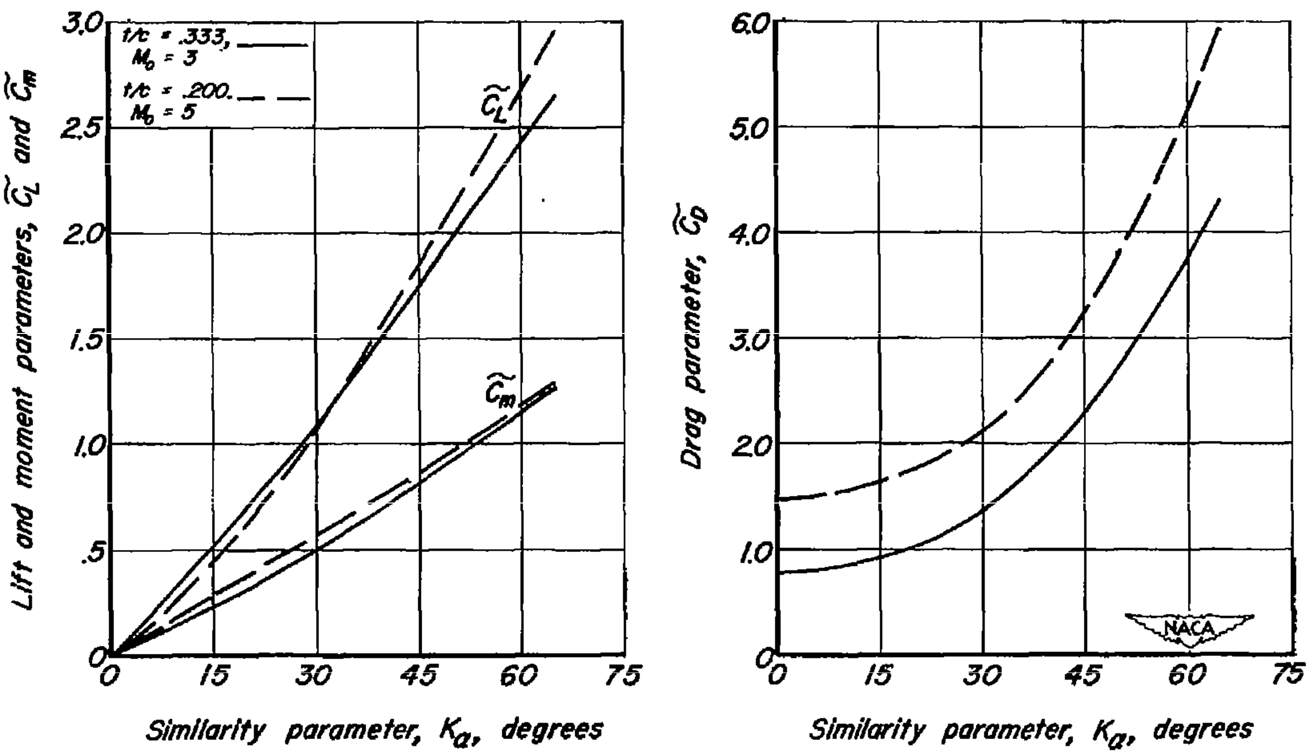
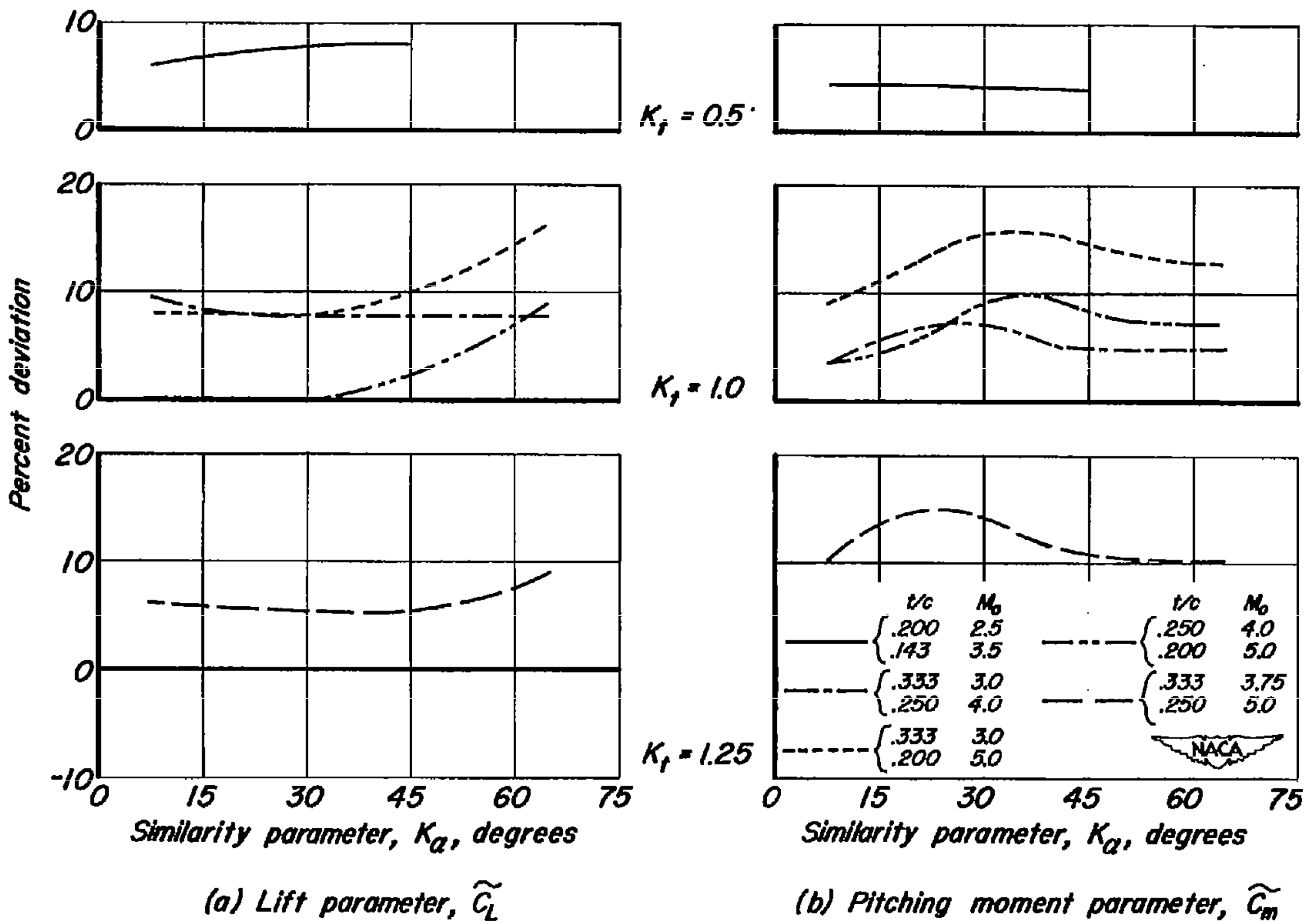
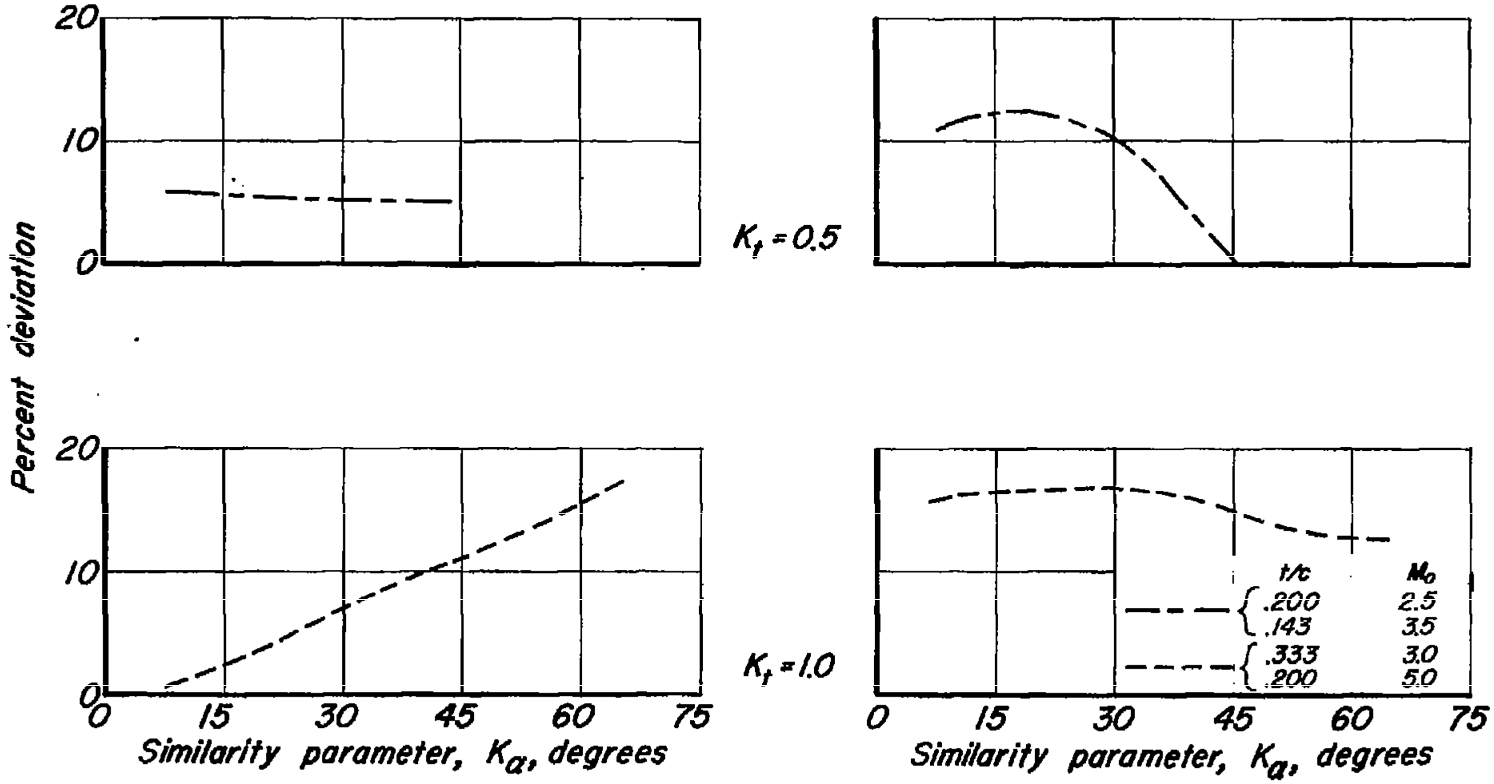


Figure 6.-Variation of the lift, drag, and moment parameters with K_α for 1/2-power bodies at K_t = 1.0.



(a) Lift parameter, $\widetilde{C_L}$ (b) Pitching moment parameter, $\widetilde{C_m}$

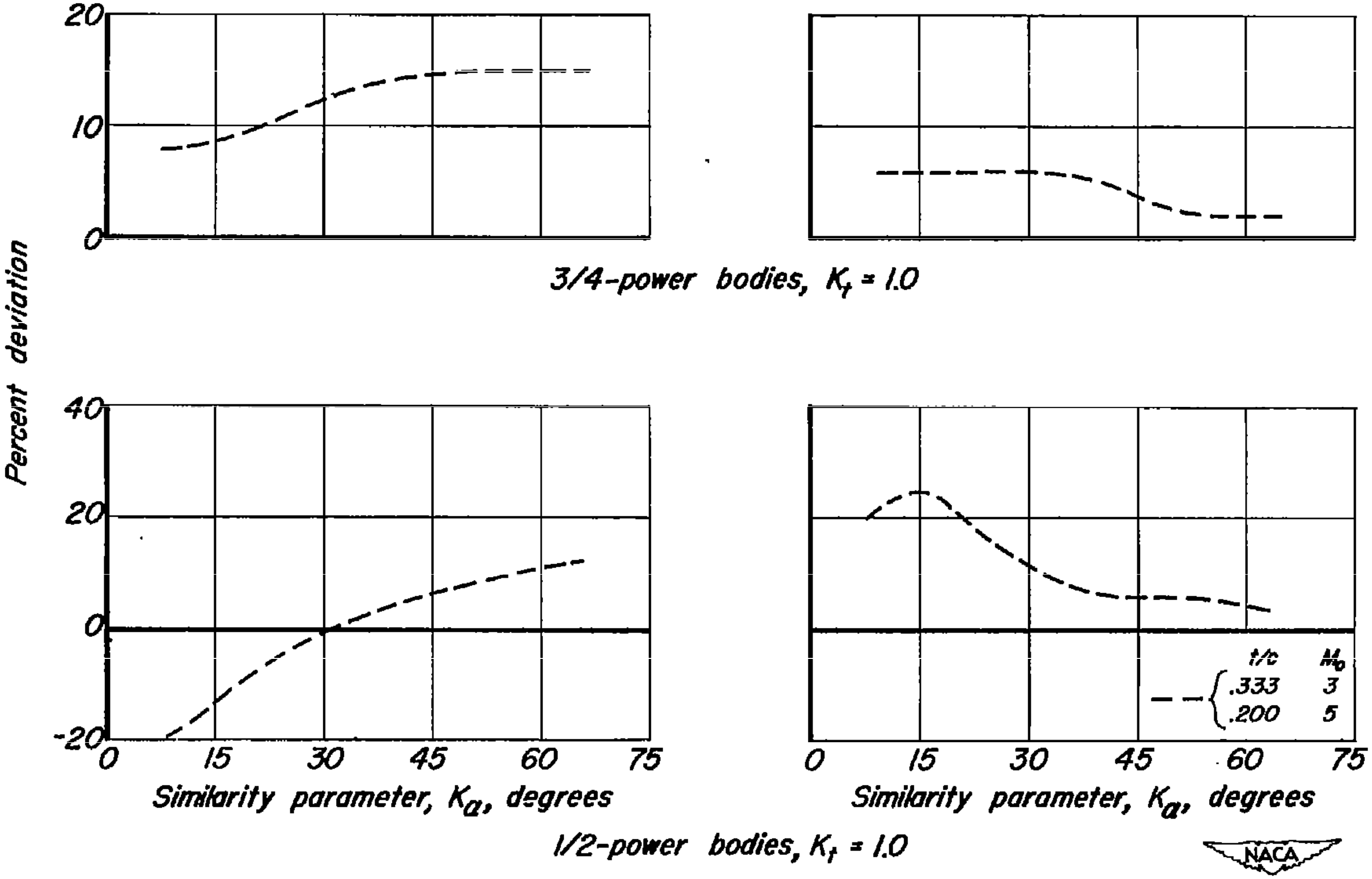
Figure 7.- Variation of percent deviation of lift and pitching-moment parameters with K_α for cones at K_t = 0.5, 1.0, 1.25.



(a) Lift parameter $\widetilde{C_L}$

(b) Moment parameter, $\widetilde{C_m}$

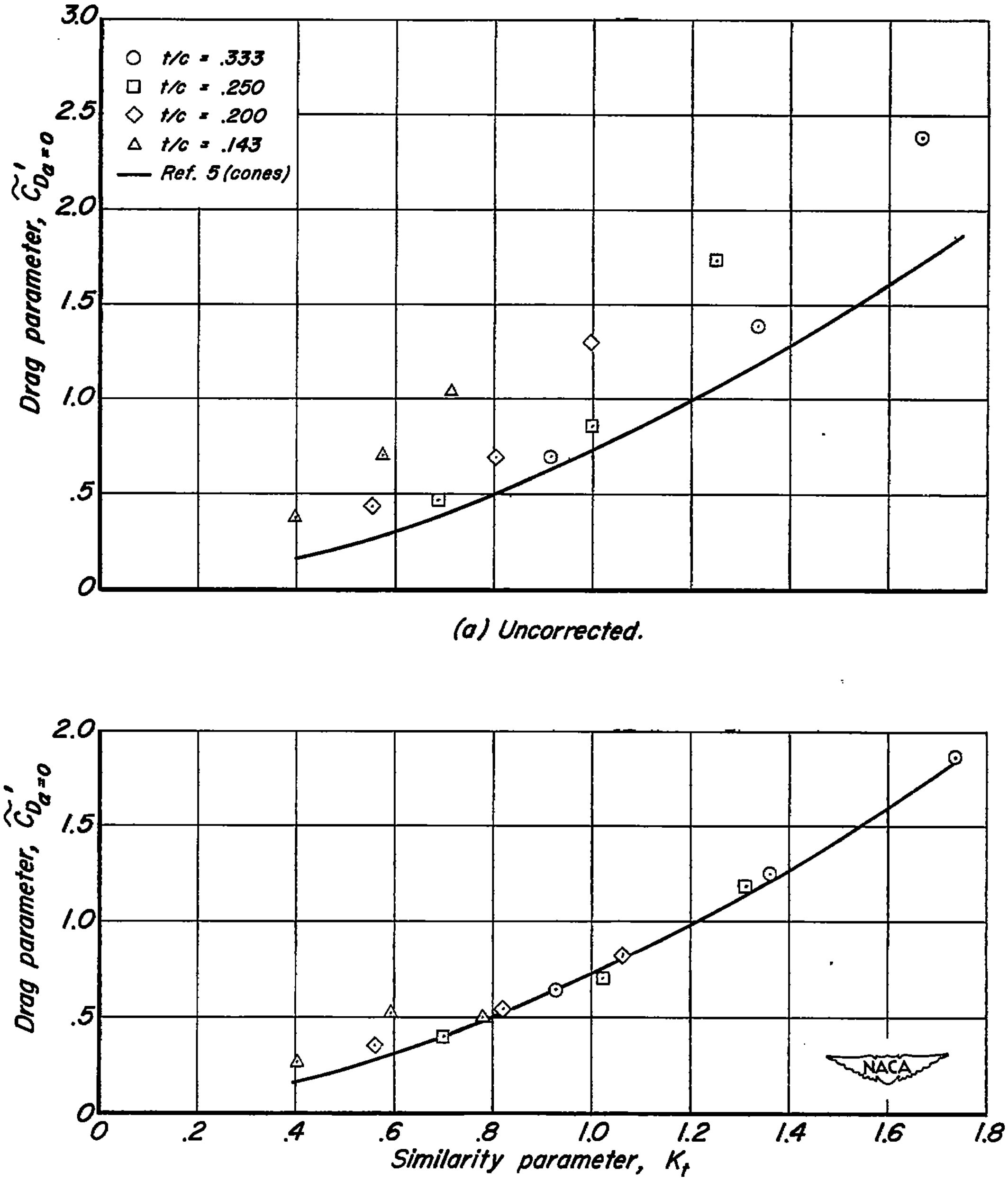
Figure 8.-Variation of percent deviation of lift and moment parameters with K_α for ogives at $K_t = 0.5$ and 1.0.



(a) Lift parameter, $\widetilde{C_L}$

(b) Pitching moment parameter, $\widetilde{C_M}$

Figure 9.-Variation of percent deviation of lift and moment parameters with K_α for 3/4-power and 1/2-power bodies at K_t = 1.0.



(a) Uncorrected.

(b) Corrected for boundary-layer effects.

Figure 10.- Variation of the drag parameter with K_t for nonlifting cones tested at M_0 = 2.75, 4.01, and 5.00.

[redacted]

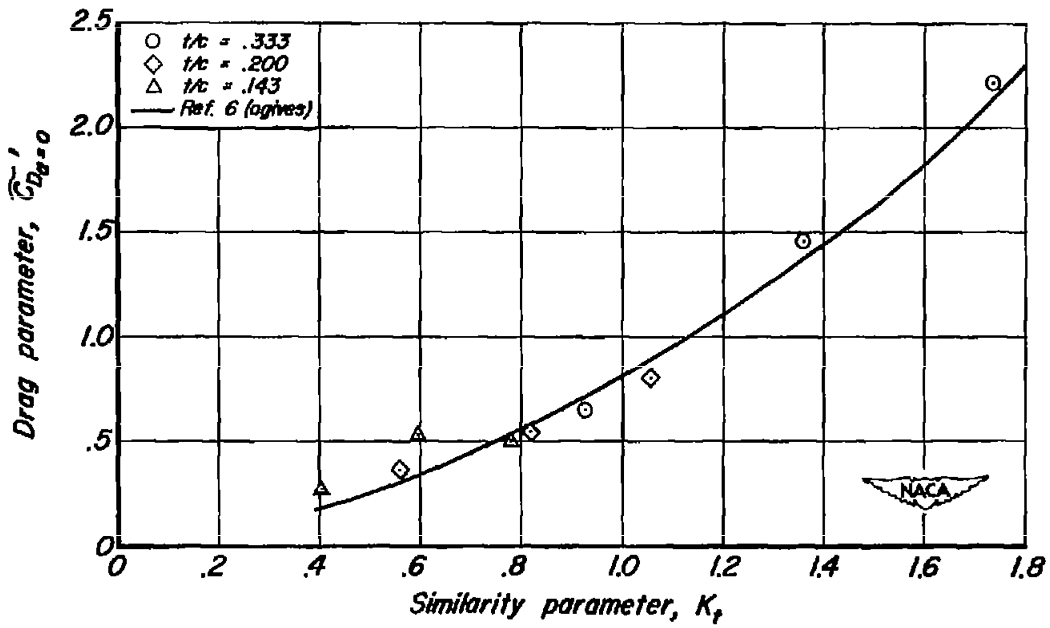


Figure 11.-Variation of the zero-lift drag parameter with K_t for ogives tested at Mach numbers 2.75, 4.01 and 5.00 (corrected for boundary-layer effects).

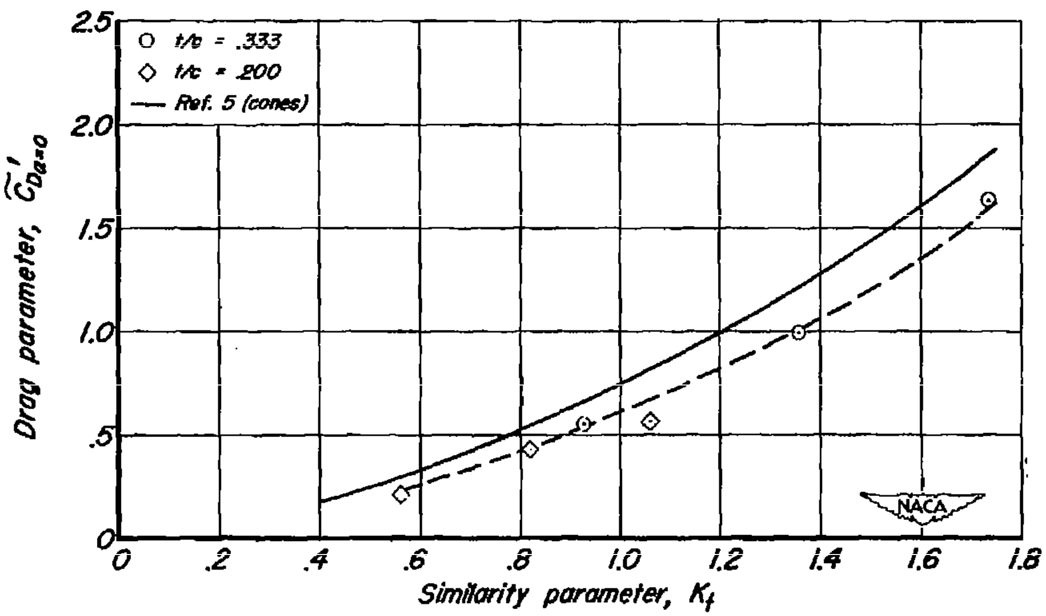


Figure 12.-Variation of the zero-lift drag parameter with K_t for 3/4-power bodies tested at Mach numbers 2.75, 4.01, and 5.00 (corrected for boundary-layer effects).

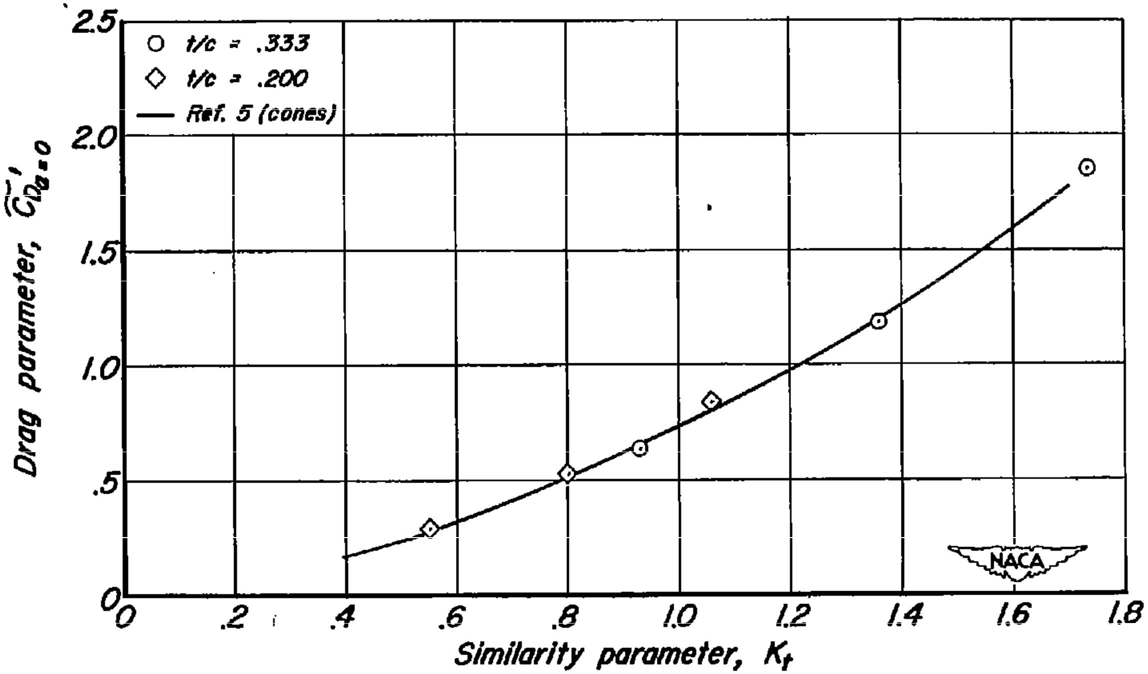


Figure 13.-Variation of the zero-lift drag parameter with K_t for 1/2-power bodies tested at Mach numbers 2.75, 4.01 and 5.00 (corrected for boundary-layer effects).

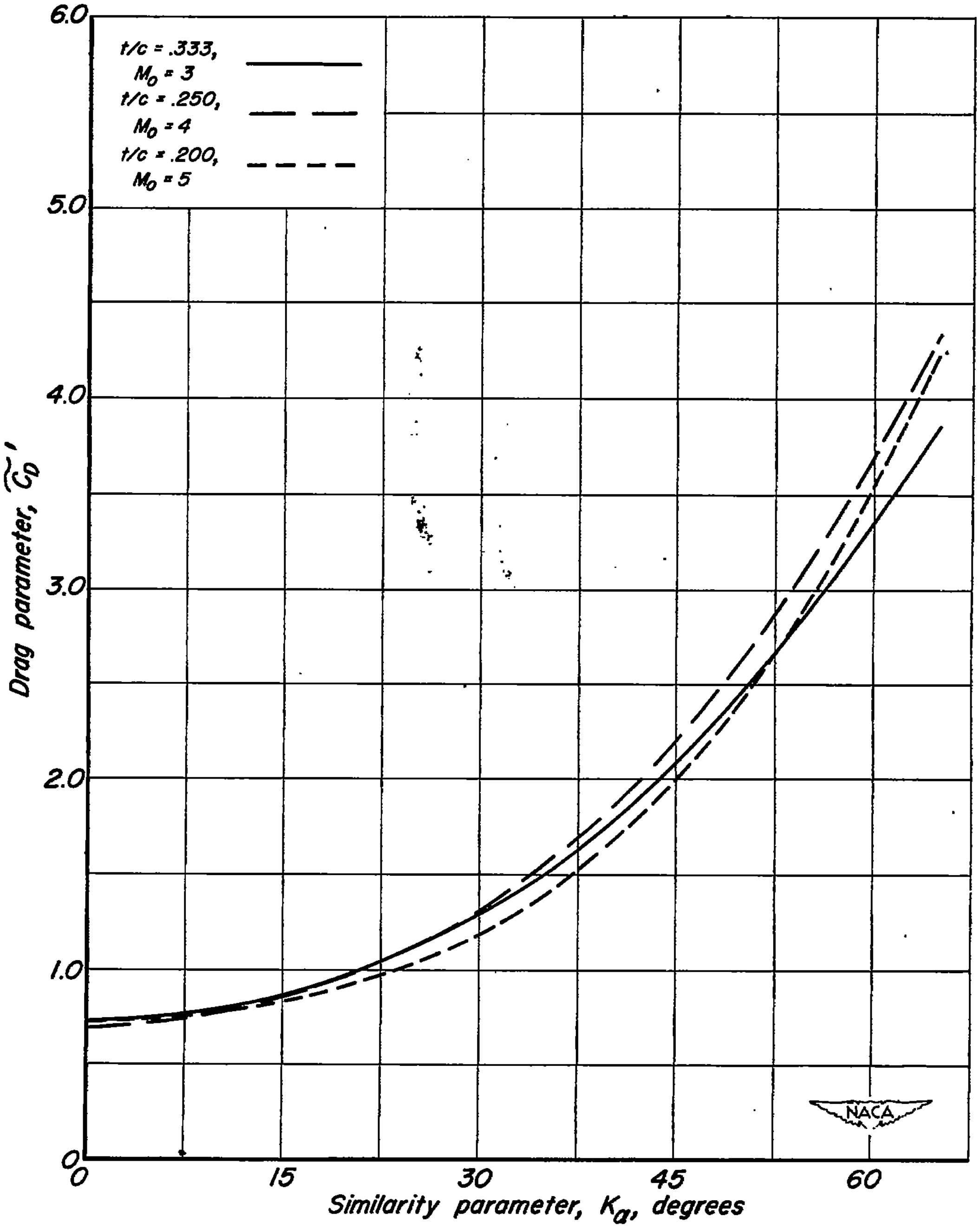


Figure 14.–Variation of the drag parameter with K_α for cones at K_t = 1.0 (corrected for boundary-layer effects).

NACA-Langley - 1-27-53 - 325